THE PERMUTATOR

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ARMOUR INSTITUTE OF TECHNOLOGY

1909

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The permutator

THE PERMUTATOR

(ROUGÉ-FAGET TYPE)

A THESIS

PRESENTED BY

F. C. ZANZIG
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TO THE

PRESIDENT AND FACULTY

OF

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FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

1909

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PREFACE.

The information given herein is the result of an experimental study of the Rouge-Faget Permutator carried on in the Dynamo Laboratory of the Armour Institute of Technology. Although of interest to the Electrical Department of this institution, where the machine was tested, it is hoped that those interested in alternating current rectifying apparatus will find this work of value, incomplete as it is.

The writers wish to acknowledge their indebtedness to those persons whose assistance made it possible to carry on even this partial investigation. Especially do we wish to express our thanks to Mr. F. O. Godfrey, a Junior of the Electrical Engineering Course, Mr. J. I. Merkin, a Senior of the Mechanical Engineering Course and the Assistants of the Electrical Department of this institution.

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Z. A. Aronian.

Armour Institute of Technology.

Chicago, Ill. May 1909.

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THE ROUGE-FAGET PERMUTATOR.

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THE ROUGE FAGET-PERMUTATOR.

INTRODUCTION.

A permutator, as the name implies, is from an electrical point of view a machine which permutes (changes) alternating current to direct current. It is a rectifier and not a converter, as will be brought out later, in that the change from alternating current to direct currant is accomplished by rectification and not conversion. This distinction is based upon the usual definitions of rectifiers and converters. In the former, the magnetic circuit interlinked with the electric circuit, if there be one, is not a function of the generated direct current; in the latter, the electric circuit is definitely related to the magnetic circuit.

It is well known that in a rotary converter a portion of the direct current is rectified alternating current and the remainder is generated due to generator action, the ratio depending upon the number of phases. In a permutator the direct current is produced by rectification only. Based upon this difference the writers have used the term, "Rectifying Apparatus or Machine", as a class to which this machine belongs.

To emphasize this difference let us consider

the following classification; motor generators, synchronous and asymmetrical apparatus. In the first the two circuits, both electric and magnetic, are distinct. In the second the two circuits are combined and the machine is no longer called a motor - generator but a rotary converter. The permutator we have classed under the third type. In the rotary converter synchronous rotation is used to induce direct currents, while in the permutator, synchronous rotation is used to collect direct currents. That is to say, the currents on the direct current side of this machine are collected from the alternating current side and not generated, either wholly or in part, as in a converter. In conclusion we may say, --- the permutator is a static transformer with a non-inductive rectifier.

THE ROUGE-FAGET-PERMUTATOR.

HISTORY.

Many inventors shortly before 1888 realized the possibility of making a machine for converting alternating currents to direct currents by taking advantage of the action of a revolving field in an inductive circuit with a fixed commutator and revolving brushes.

An excellent resume of the different patents issued to numerous inventors has been given in the "Zeitschrift für Electrotechnok" in the numbers of Aug. 28th and September 2, 1906.

It seems that the failure of the early inventors of this machine was due to lack of sufficient knowledge in the distinction between the permutator and the rotary converter. In 1888 Zipernowsky and Deri conceived the possibility of making use of the above named principles. In their patent there is no distinction between a rotary converter and a permutator. In reality their machine is a rotary converter with two circuits.

Messrs. Hutin and Le Blanc, in 1892, were the first to give a correct solution of the problem by using sinusoidal windings. This apparatus, on account of constructional difficulties, did not have a commercial development as was rightfully expected from it.

THE ROUGE-FAGET PERMUTATOR.

Later Messrs. Blondel and Souther took up the incomplete solution of Zipernowsky and brought into light the part played by the asymmetrical windings of the magnetic circuits and also solved the problem of load disturbances. Unfortunately, led away by studies whose immediate interest was greater, they did not push the solution of the problem to the end.

Mr. Maurice Le Blanc in 1902 took up the solution of Zipernowsky's problem and gave a correct but extremely complicated solution.

Messrs. Rouge-Faget took up the same problem the following year and succeeded in developing the true permutator. This machine these people are now manufacturing on a commercial basis.

- - - - - - - - - - -

It is this machine with its characteristics which we wish to confine ourselves to, ---- in particular, the machine having the following name plate data.

PERMUTATRICE

SYST^{ME} ROUGÉ-FAGET BREVETÉ

EN FRANCE S.G. D.G. ET TOUS PAYS.

Alt.	Freq. 60	Cont.	Amp. 70
	Volt 90		Volt 120

S^{TÉ} ANONYME-EGYPTIENNE-D'ELECTRICITE

PARIS,
BUREAUX,
43, Rue du Rocher.

SIÉGE SOCIAL,
ALEXANDRIE,
EGYPTE.

#1049.

THE ROUGE-FAGET PERMUTATOR.

GENERAL DESCRIPTION.

The permutator# (see Figs. 1 and 2) consists of three essential parts, namely:-

1. A transformer having a hollow iron cylindrical core.

2. A synchronous motor which rotates the brushes about a fixed commutator.

3. A set of revolving brushes which collect the direct current.

TRANSFORMER.

The core of the transformer is built up of sheet iron punchings, laminated at right angles to the axis of the annular ring. It contains slots running parallel to the axis and uniformly placed about the center exactly as in the stator of an induction motor. It differs from the core of an induction motor stator, in that the slots are not open to the inner periphery but completely closed. The quantity of iron between the slots and inner periphery being small, compared with the exterior portion of the ring, allows an appreciable flux to enter the core of the armature which rotates within the hollow transformer core. The winding on this

---

Figures 1-5 have been taken from U.S. Patent Papers #689566.

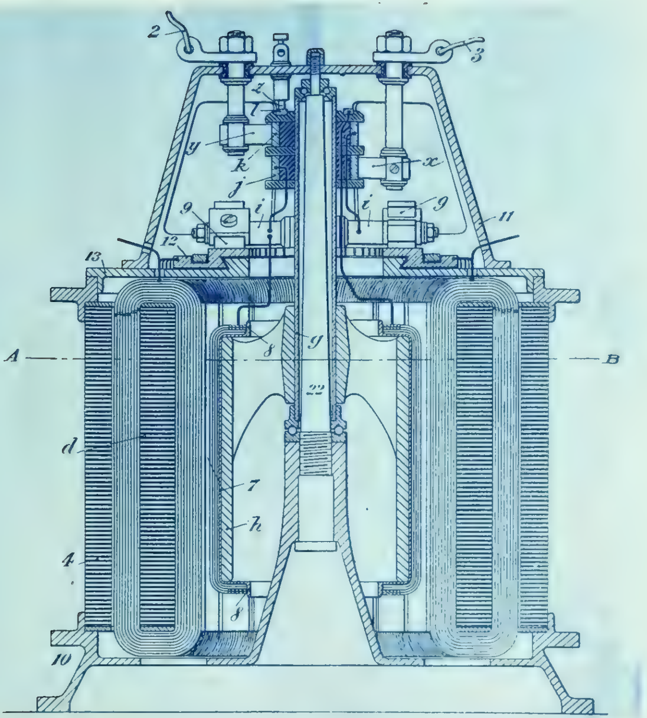

FIGURE I

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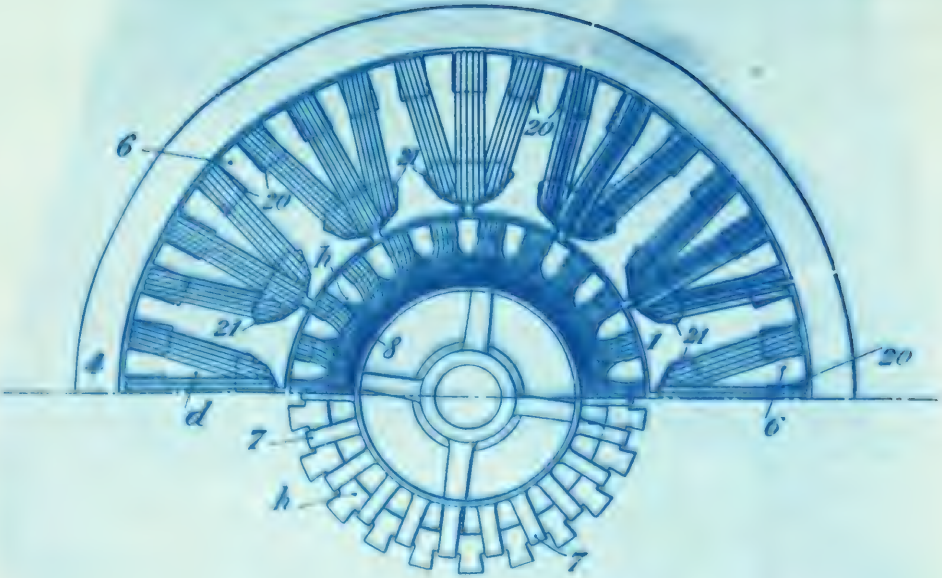

SECTION THROUGH AB OF FIG I

FIGURE 2

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core will be discussed very completely under the head of "Core Windings". Suffice it to say, that these windings are so arranged, that when connectedto an alternating current system a rotating magnetic field will be produced within the core. The core with its windings is mounted vertically upon a solid frame.

MOTOR.

The motor whose armature rotates the brushes about the fixed commutator is a synchronous motor. Its armature is fixed to a vertical shaft and rotates within the transformer core thus allowing the use of a small air gap and also preventing unequal air gap flux distribution due to wear on the bearings. The core of this armature completes the magnetic circuit of the rotating field, at least, that part of the flux which does not remain in the transformer core beneath the slots. It may be stated here that the air gap produces no undesirable effects except to increase the exciting current. The winding on the armature of this motor is an ordinary drum winding and receives its excitation from the direct current source of the machine through two collector rings. The coils are exceptionally well insulated and in each slot above the coils there is wedged a strip of

brass which holds the coils in place; these brass strips also function as conductors of a simple squirrel cage rotor of an induction motor.

COMMUTATOR AND BRUSH HOLDER.

The brush holder is fixed relatively to the armature but capable of angular adjustments about the motor shaft. The brushes are equally displaced about the commutator and rotate at a uniform velocity when the machine is in operation. When the machine is not in operation the brushes are held in place by spring tension. The pressure these brushes would exert upon the commutator,due to centrifugal force, would decrease as the speed increased, or rather, as the square of the speed, divided by the radius of gyration, until finally a point would be reached when contact would be broken. The arrangement used to prevent this action is as follows. One end of a lever rests upon the brush and is held firmly against the same by spring tension. The other end of the lever carries a weight and at some point between the lever is slotted. The weighted end of this lever may be rotated against the spring tension within certain limits about the fulchrum at the brush. This allows the multiplying power of the lever to decrease

for an outward movement of the weight, and thus, for a given velocity, decreases the brush pressure minus that due to the increase of brush tension brought about by the change. Although the radius of gyration of the weight has been increased the net result, nevertheless, is a diminished brush pressure. The action then is an increase of brush pressure up to a fixed limit with an increase of frequency and at this frequency the ratio of the lever arms changes so as to bring about a decrease of pressure, which again continues to increase with further increase of frequency. This frequency of transition may, by properly adjusting a set screw, be made the same as the normal operating frequency of the machine.

On the upper portion of the core frame is mounted a commutator. One half of the segments are connected to taps on the winding of the core and each segment of the other half is connected to its adjacent segment, in a direction opposite to that of rotation, through a small resistance, commonly called, commutating resistance.

THE ROUGE-FAGET PERMUTATOR.

CORE WINDINGS.

The diagram of the windings of the machine under the test is herein contained (Figure 6).(Figures 3, 4 and 5 show diagrammatically the windings for a single, two and three phase permutator respectively). There are shown ninety slots for the sake of clearness,- in reality there are only forty-five, both the external and internal coils occupying the same slot. It is seen that all these coils are alike each coil consisting of three turns and having a pitch of seven slots. The coils consisting of three conductors are connected in series and for a complete circuit about the core there are four coils approximately 90 degrees apart. The terminal of the fourth coil is connected to the beginning of the coil adjacent to the first. Thus it is seen that the winding is symmetrical.When properly supplied with alternating current a four pole rotating field will be produced. These coils the patentees of this machine have called "Vectorial" coils or windings,--- the reason for giving them this name will be evident when we analyze their functions.

In this machine the alternating current is supplied directly to these windings. In the more gen-

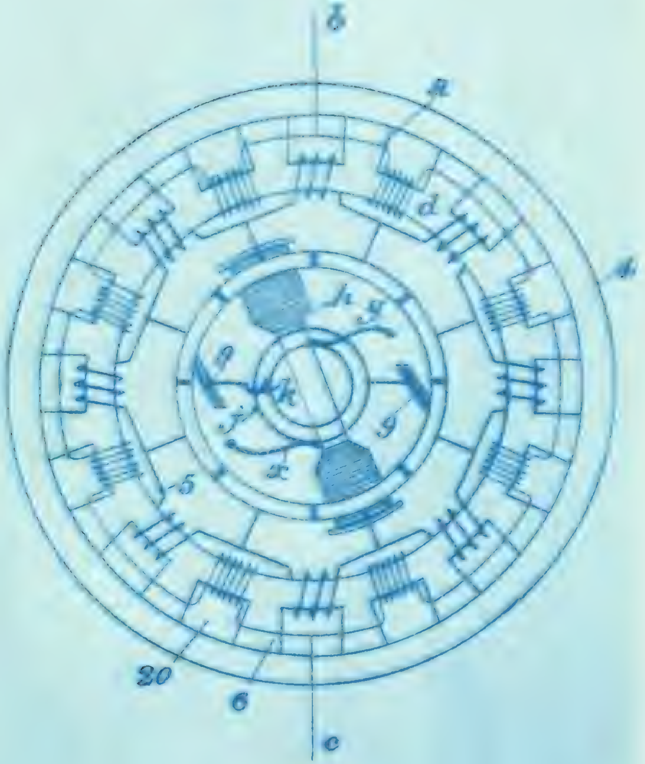

FIGURE 3

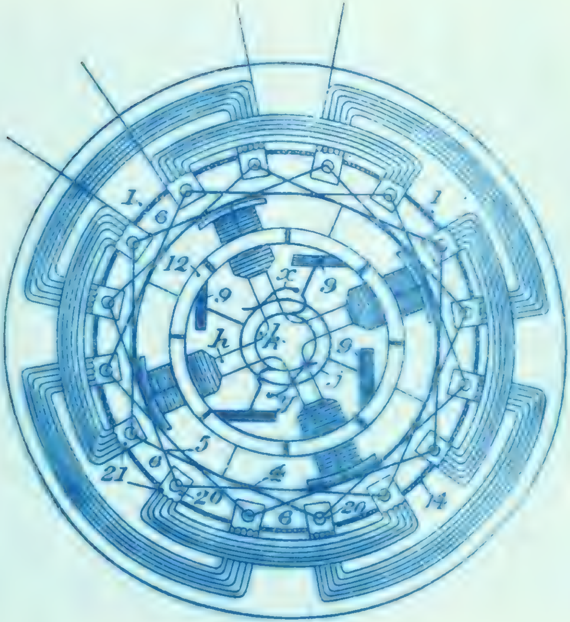

FIGURE 4

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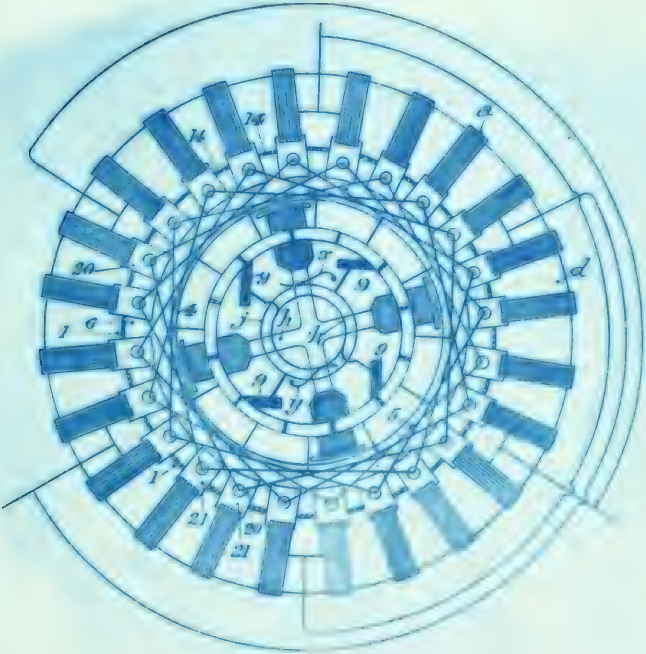

FIGURE 5.

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[illegible]
[illegible]

WINDING DIAGRAM
FOR
PERMUTATOR
#1049
A.C. 60 CYCLE
90 VOLTS
D.C. 70 AMPERES.
120 VOLTS.

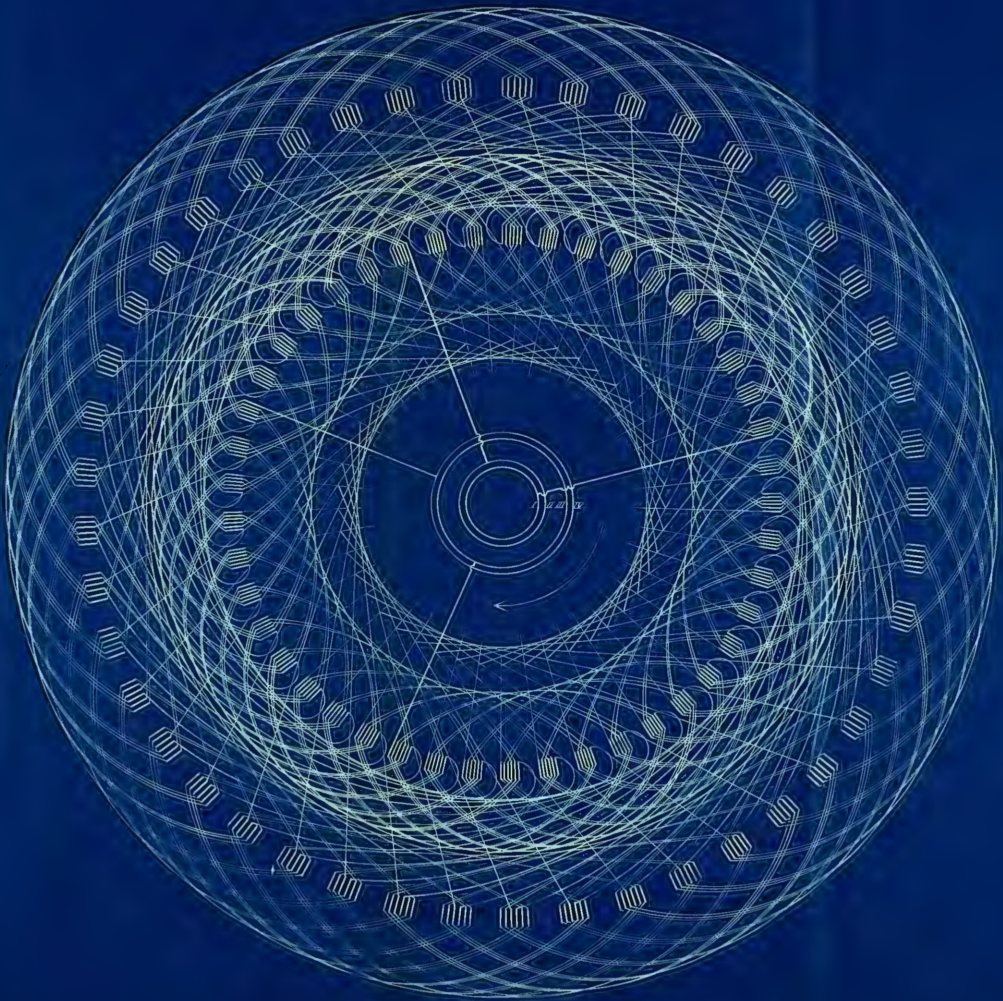

FIGURE 6

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eral type of permutator an independent winding is placed upon the core usually in separate slots above the slots containing the vectorial windings, or, for mechanical reasons, midway between but still in the exterior element of the core. To elucidate the actions within the core the general type of permutator will be used as an example.

The second winding mentioned in the last paragraph forms the primary winding of the cylindrical transformer and differs in no way from that of an induction motor stator winding. The potential across the primary, as in any transformer, may have any value whatsoever; the secondary voltage depending upon the ratio of turns may be made equal to that value which gives the desired rectified voltage which is 1.414 times the altternating voltage per phase.

Since the primary coils are so wound as to create in the core a uniform rotating magnetic field there will be generated in the secondary (vectorial) coils an electromotive force having a sinusoidal distribution. That is,with a sine wave impressed upon the primary there will be induced in the symmetrical vectorial windings an equivalent sinusoidal direct cur-

rent distribution.

For the time being let us consider an ordinary transformer. If upon the primary a true sinusoidal electromotive force is impressed a similar electromotive force will be generated in the secondary by induction under ideal conditions. Not considering variations in the iron, nor such effects as hysteresis, eddy currents, etc., the current in the secondary will at all times differ from the primary current by 180 electrical degrees.

Now let us assume a resistance placed across two points on the commutator a fixed distance apart and covering an arc of 180 electrical degrees, or 90 mechanical degrees on the accompanying diagram (Fig.6), such that there exists across the resistance a maximum voltage, that is, the square root of two times the effective voltage per phase. Also let this circuit move synchronously with the wave, that is, be in phase with it at every instant. We will then observe for this condition a direct current circulating through the resistance since the voltage across it is constant.

We have not considered the inductive effect produced by the rectangular shaped wave up to the present time. It is evident that serious disturbances

would arise in the circuits, both electric and magnetic, if not compensated for. The compensation is brought about by winding the secondary with chord windings. The winding diagram may represent the secondary with these chord circuits. The direct current now circulating in this winding will give a sine distribution and will at all times be approximately a sine wave differing by 180 degrees from the primary current. Thus we have on the alternating side n(I sin wt) and on the direct current side I_1(n_1 sin wt). It is for this reason that these windings have been given the name "Vectorial Windings".

The figure given below, (Fig. 7.), may simplify the explanation of the action which takes place in these coils.

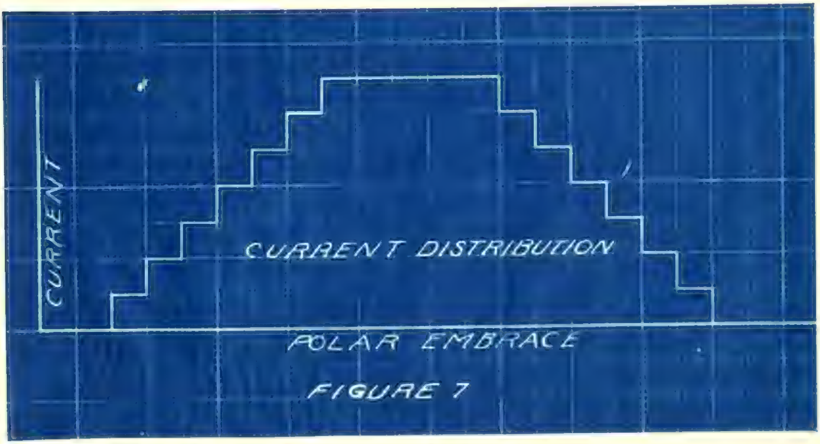


FIGURE 7

THE ROUGE-FAGET PERMUTATOR.

The representation here given is the general scheme of presenting flux distribution and the like. It is known that a distribution as here given produces practically a sine wave. When considering this effect in connection with the inducing system it is evident that we have equivalent transformer action. These coils being connected in series carry the same direct current, and assuming a constant load for any instant, produce a revolving current sheet in synchronism with the frequency of the impressed voltage. Since the currents have a sine distribution which differ by 180 degrees they can be represented by vectors. In practice we find, like in a transformer, this angle to be less than 180 degrees, and that the resulting current is the exciting current.

A special coil was placed in the same slots containing these chord windings, and the oscillograph used in connection with these coils, showed that the flux distribution was practically sinusoidal, in other words, the distribution was as it ought to be.

In the winding diagram it is seen that these chord windings are connected directly to the alternating current source and that the primary coils are absent. For this reason it was not desirable to analyze the

transformer action by referring to this winding except to show the relations between the chord circuits of the secondary. However, attention is called to the arrangement of the terminal connections. The angle between the terminals of each phase is 180 electrical degrees and between phases it is 270 degrees or -90 electrical degrees. Hence the vector sum of the e.m.f.'s is constant and equal to the terminal voltage on the direct current side. This winding, it may be said, is the scheme generally used for the secondary of any permutator. In conclusion, we may say, that the secondary may be looked upon as a stationary armature about which a magnetic field rotates.

Whenever two circuits are balanced inductively we have what might be called, " Inductive Equilibrium ". A good example of this is illustrated in some of the latest types of alternating current series motors wherein sparkless commutation is effected by properly balancing the inductive circuits.

The vectorial windings perform this function, that is, produce an inductive circuit which is so related to the inducing system that for all values of direct current in these windings there results sparkless commutation. The potential between adjacent seg-

ments, as one passes from one set of brushes to another, is a function of the sine of the angle swept over. At the top of the wave the potential between the segments is small, and since all the brushes are in this region of the wave, the current in the coil short-circuited by the brush is also small and in the direction of the main current.With the aid of commutating resistance sparkless commutation is obtained without adjusting the brushes even with 50% overload on the machine. This only holds true for an approximately sine wave.

OPERATION.

Any transformer may be directly connected to the line without producing disastrous results within the transformer itself.Confining ourselves to the transformer we may mention that the current which flows for the first instant is logarithmic, the decrement being large, causes the current to become normal within a few cycles. By directly connecting the terminals of the permutator to the line we may expect no more serious results than those which occur in the transformer;

that is, no auxiliary starting device is necessary,--- the closing of the switch starts the machine and it comes up to synchronism within a few seconds.

When the switch is closed on the alternating current side the brush motor starts as an induction motor because the armature is also a squirrel-cage rotor. The same is true for a single phase machine provided a shading coil, or its equivalent, is used. Attention was called to the well insulated coils of this armature. Ordinarily the circuit of these coils is closed,practically short-cicuited, and since each coil consists of many turns in series there would result a breakdown in the insulation, should, for some reason the circuit be opened and the insulation insufficient to withstand the high electromotive force produced by the rotating field when closing the switch.

At the instant the circuit is closed an alternating current exists on the direct current side of the machine.The frequency of this current is equal to the product of the line frequency and slip and decreases as the motor approaches synchronism. The impedance of the armature coils therefore decreases becoming negligible near synchronism. This allows

sufficient current to circulate in the coils to cause the armature to fall into step with the rotating field and thus operate at synchronism.

In a two phase machine the terminals of one phase may be reversed should the machine come up in the wrong direction. In a three phase machine any two terminals may be reversed. The direction of rotation, if not known, may easily be determined by noting the connections of the commutating resistance.

There is one more point to consider when starting the machine.If the direct current terminals are connected to a heavy load, that is, a low resistance, and the alternating current switch is closed, an alternating current of large value will flow through this low resistance provided the impedance is low. Remembering that the current carrying capacity of the commutating resistance is low it is evident that these resistances are in danger of destruction,- hence,the machine should be started up unloaded.

In case the potential of the direct current terminals is desired to be reversed without changing the connections it is only necessary to open the alternating current switch for a few moments and again close

it. If the machine is separately excited it is evident that the reversal cannot be brought about by this means. The principle upon which the first statement is based is as follows. At any particular instant the direction of the current is fixed. The opposite poles of the armature and rotating field are locked magnetically. If now the alternating current circuit is opened for an instant the speed of the motor will decrease;on again closing the circuit the brushes may or may not differ from their previous position by 180 electrical degrees. If they do the poles of the armature are reversed because the direct current is reversed and the machine will operate as before. It may be necessary, however, to make several trials before this condition is obtained.

The parts of the armature which make it a squirrel cage rotor have been discussed with reference to starting the motor. This rotor also serves as an efficient damping device for a sudden change of voltage or frequency. To a limited extent the coils of the armature serve the same purpose. It must not be lost sight of that the kinetic energy of the moving system is comparatively small and because of this fact the

damping device is enormously more effective than in any rotary converter. This is only one of the features which makes commutation sparkless. In fact this characteristic is not only advantageous in the machine itself but also serves admirably when connected in parallel with other machines to prevent an interchange of energy between them.

THE ROUGE-FAGET PERMUTATOR.

TESTS AND RESULTS.

The direct current load consisted of incandescent lamps,-- any other current consuming apparatus could have been used whether inductive or not.The use of lamps afforded an easy means to keep the load constant inasmuch as the line voltage was exceedingly unsteady. Although all instrumental errors were eliminated,errors of at least 2% have entered due to the above named variations. It was made possible to keep the error within this limit by taking at least five sets of readings for a given condition.

Distorted waves affect the characteristics of a transformer very appreciably,so with this machine, a distorted wave may show up the machine advantageously or vice versa. At the outset it was intended to investigate the effect of superimposed higher harmonics upon the fundamental wave but existing conditions made it impossible to carry on this investigation. The tests were made with a wave containing a fifth harmonic and some of the results herewith given differ from those which would have been obtained had a sine wave been used.It must then be remembered that no fixed lines can be drawn between some of the char-

acteristics of the machine itself and those due to the presence of higher harmonics. However, one characteristic is strikingly brought out by this effect to which the reader's attention will again be called.

The power measurements were taken on one phase only which was allowable since both phases were equally loaded. Only one set of readings were taken with the armature of the synchronous motor separately excited,-- the corresponding data for this set is given on PLATE IV. However, a 15 ohm resistance was placed in this circuit for all the other runs.

This latter statement perhaps needs further emphasis in connection with the operating characteristics of the tests. Since the brush motor is a synchronous motor the angle between the two revolving fields is dependent upon the excitation which in turn depends upon the brush position. That is, if the brushes of this machine are given a lead of 5 degrees by measurement it is not necessarily 5 degrees when the machine is in operation. The new position of the brush will change the voltage on the direct current side and therefore increase or decrease the angle between the fields

thus giving a resultant lead of more or less than 5 degrees depending upon the change of voltage. The resistance already spoken of is used under normal conditions and was therefore used when making the various test runs. To prevent the motor from slipping a pole or dropping out of synchronism entirely, should the line voltage drop excessively, this resistance may be short-circuited and thus increase the excitation. To emphasize, let it be remembered that angles of brush lead refer in the following discussion to actual measurements taken on a divided scale on the brush holder.

PLATE I contains the data obtained by varying the load for different brush positions. The headings are sufficiently descriptive to warrant no further remarks except to say that the angle 10° is the neutral plane of commutation and for this position the direct current voltage is maximum. From this data the curves given on Curve Sheets I and I-A were plotted.

PLATES II-A and II-B contain the data obtained by varying the frequency, the former under full load and the latter under half load. The curves as shown

PLATE I

PERMUTATOR

#7049

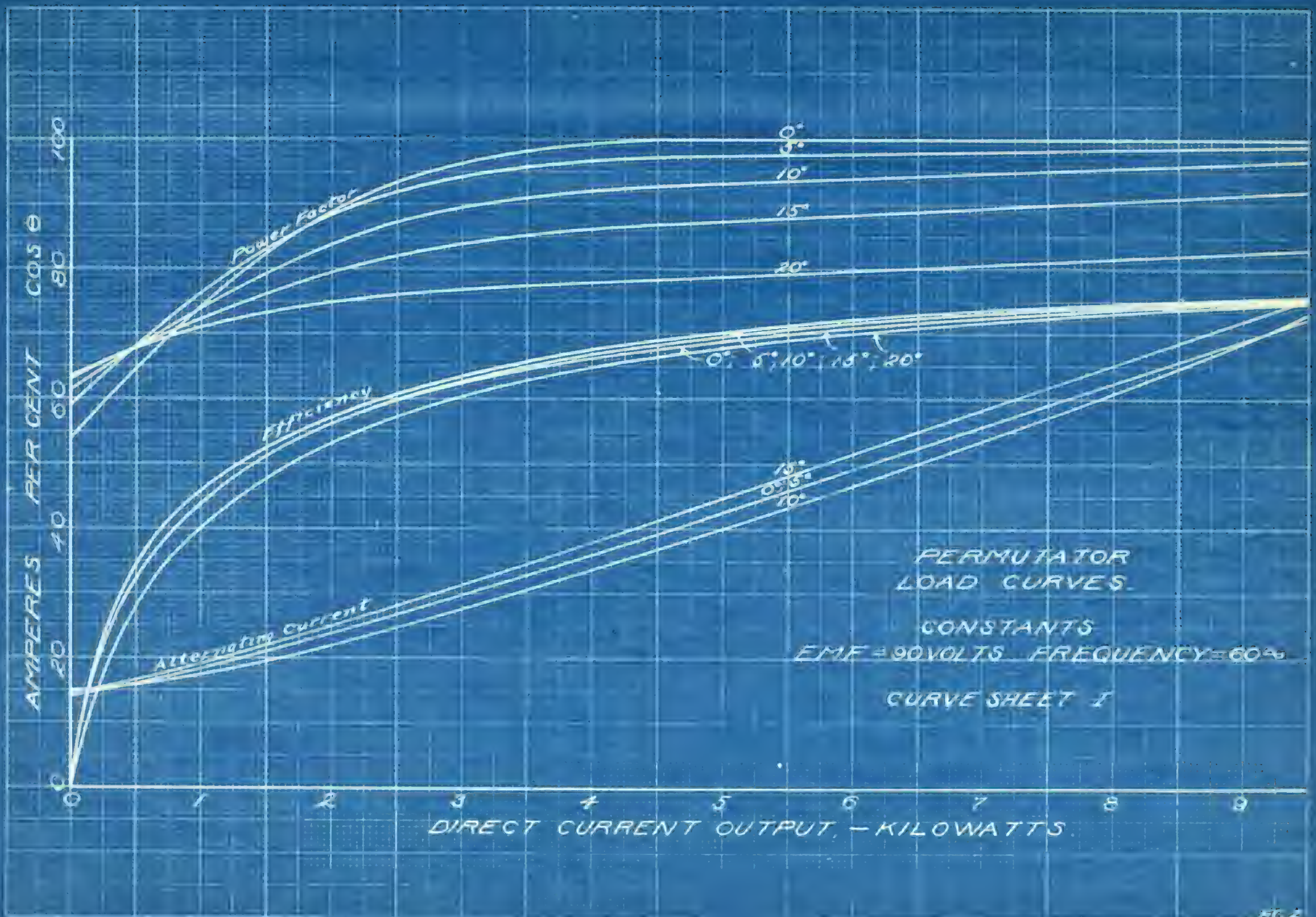
A.C. 60 CYCLE 90 VOLTS   D.C. 70 AMPERES 120 VOLTS

CONSTANTS

EMF = 90 VOLTS   FREQUENCY – 60~

Brush Angle	Direct Current			Alternating Current				Power Factor	Eff
Deg.	Amp	Volts	Watts	Amp per Ø	Watts per Ø	Watts Total	Watts 90·Amp	COSθ	%
0	0	114.1	0	15.0	730	1460	1350	.540	0
	17.5	111.2	1950	21.8	1730	3460	1960	.883	56.6
	35.0	107.5	3760	32.2	2880	5760	2900	.993	65.4
	52.5	104.3	5480	43.0	3870	7740	3870	Unity	71.0
	70.0	101.1	7080	55.0	4950	9900	4950	Unity	71.8
	87.5	96.7	8450	64.0	5750	11400	5750	Unity	74.0
5	0	122.0	0	14.2	760	1520	1280	.594	0
	17.5	118.2	2070	22.4	1860	3720	2090	.895	55.8
	35.0	114.3	4000	34.2	2990	5980	3080	.970	67.0
	52.5	110.3	5790	45.0	3960	7920	4050	.977	73.0
	70.0	106.4	7450	56.0	4970	9940	5040	.985	75.0
	87.5	105.9	9260	68.5	6160	12320	6160	Unity	75.0
10	0	123.6	0	14.0	780	1560	1260	.616	0
	17.5	119.5	2090	24.3	1880	3760	2190	.849	55.8
	35.0	115.6	4050	36.2	3030	6060	3260	.929	67.0
	52.5	112.9	5920	48.0	4050	8090	4320	.939	73.2
	70.0	109.8	7680	60.3	5150	10300	5430	.949	74.6
	87.5	106.5	9320	71.0	6260	12520	6390	.980	74.6
15	0	122.3	0	14.5	830	1660	1300	.639	0
	17.5	116.3	2040	25.6	1830	3660	2300	.793	56.0
	35.0	112.4	3940	37.8	2950	5900	3400	.868	67.0
	52.5	109.0	5730	50.0	3950	7900	4500	.880	71.6
	70.0	106.9	7480	62.0	4990	9980	5580	.893	74.8
	87.5	104.0	9100	72.5	6060	12120	6530	.929	75.0
20	0	114.3	0	14.7	840	1680	1320	.633	0
	17.5	106.8	1870	27.0	1820	3640	2430	.750	51.4
	35.0	101.2	3540	40.3	2820	5640	3630	.775	62.8
	52.5	93.3	4900	54.0	3620	7240	4860	.743	67.8
	70.0	90.7	6330	64.3	4370	8740	5780	.735	72.6
	87.5	92.8	8110	74.8	5520	11040	6780	.820	73.6

F.C.Z.



PERMUTATOR
LOAD CURVES.

CONSTANTS
EMF = 90 VOLTS FREQUENCY = 60 ~

CURVE SHEET I

FIG 2

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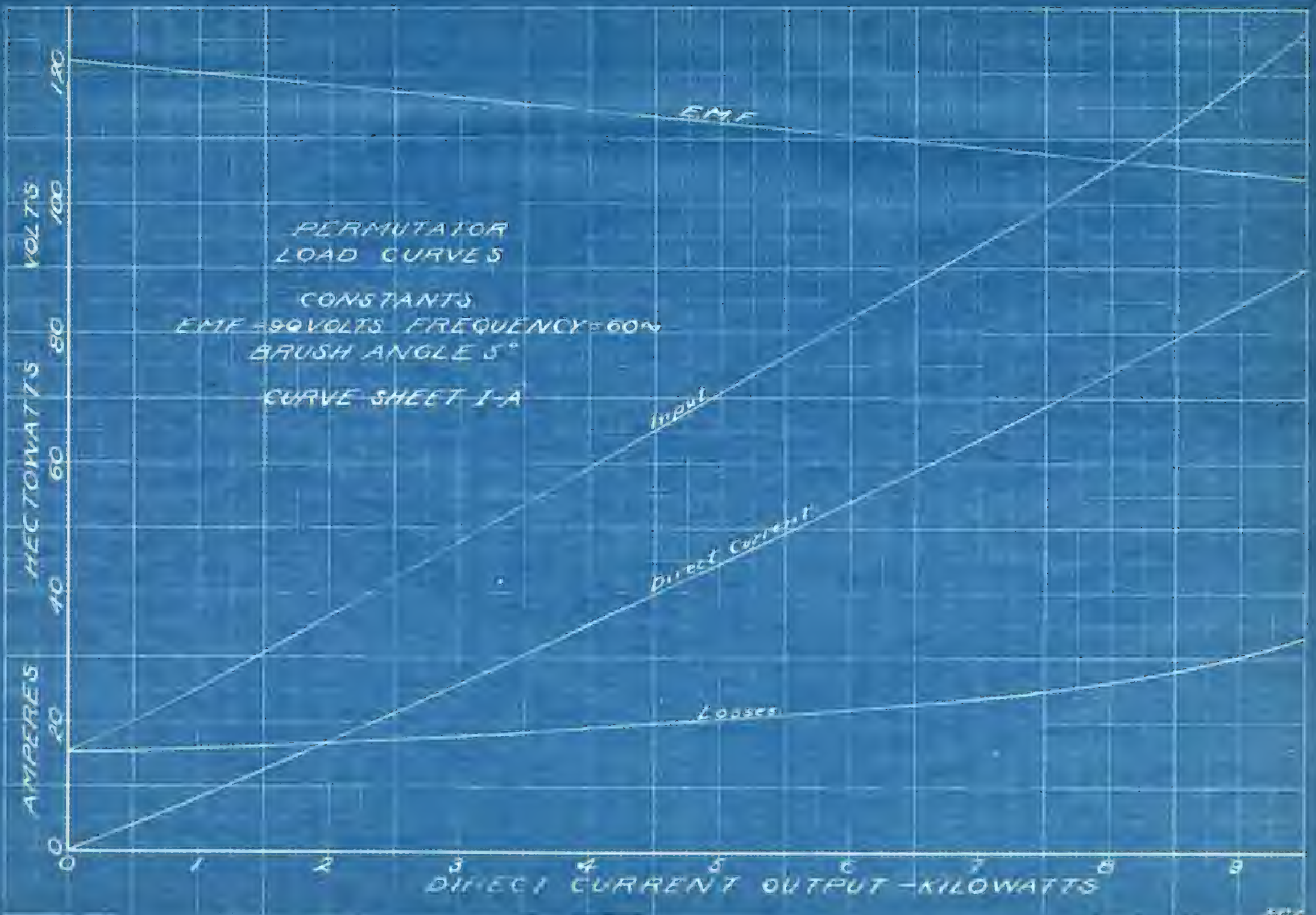
PERMUTATOR
LOAD CURVES
CONSTANTS
EMF = 90 VOLTS FREQUENCY = 60~
BRUSH ANGLE 5°
CURVE SHEET I-A
EMF
Input
Direct Current
Losses
VOLTS
HECTOWATTS
AMPERES
0
20
40
60
80
100
120
0
1
2
3
4
5
6
7
8
9
DIRECT CURRENT OUTPUT-KILOWATTS

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PLATE II -A

PERMUTATOR

#049

A.C. 60 CYCLE 90 VOLTS
D.C. 70 AMPERES 120 VOLTS

CONSTANTS

E.M.F. = 90 VOLTS. BRUSH ANGLE 5°
DIRECT CURRENT = 70 AMP.

Alternating Current					Direct Current		Power Factor	Eff
Fre C.P.S.	Amp per Ø	Watts per Ø	Watts Total	Watts Volts-Amp	Volts	Watts	COS θ	%
40	65.0	5210	10420	5850	107.9	7550	.891	72.4
45	57.4	4960	9920	5160	107.7	7530	.960	75.8
50	55.7	4910	9820	5020	107.3	7510	.978	76.5
55	55.4	4900	9800	4980	106.3	7450	.984	76.0
60	55.4	4930	9860	4980	105.8	7400	.990	75.0
65	55.8	4990	9980	5030	104.5	7320	.993	73.4
70	55.3	4900	9800	4980	102.5	7180	.984	73.2

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PLATE II-B

PERMUTATOR

#1049

A.C. 60 CYCLE 90 VOLTS D.C. 70 AMPERES 120 VOLTS

CONSTANTS

E.M.F.=90 VOLTS, BRUSH ANGLE 5°
DIRECT CURRENT=35 AMP

Alternating Current					Direct Current		Power Factor	Eff
Fre CPS	Amp per Ø	Watts per Ø	Watts Total	Watts Volts-Amp	Volts	Watts	COS θ	%
45	44.0	3160	6320	3960	113.0	3960	.798	62.6
50	40.5	3180	6360	3650	116.0	4060	.870	63.7
55	40.0	3210	6420	3600	119.0	4170	.892	65.0
60	40.0	3240	6480	3600	121.7	4260	.900	65.8
65	39.5	3240	6480	3560	121.0	4240	.910	65.5
70	38.5	3200	6400	3470	119.0	4170	.923	65.2

FGZ

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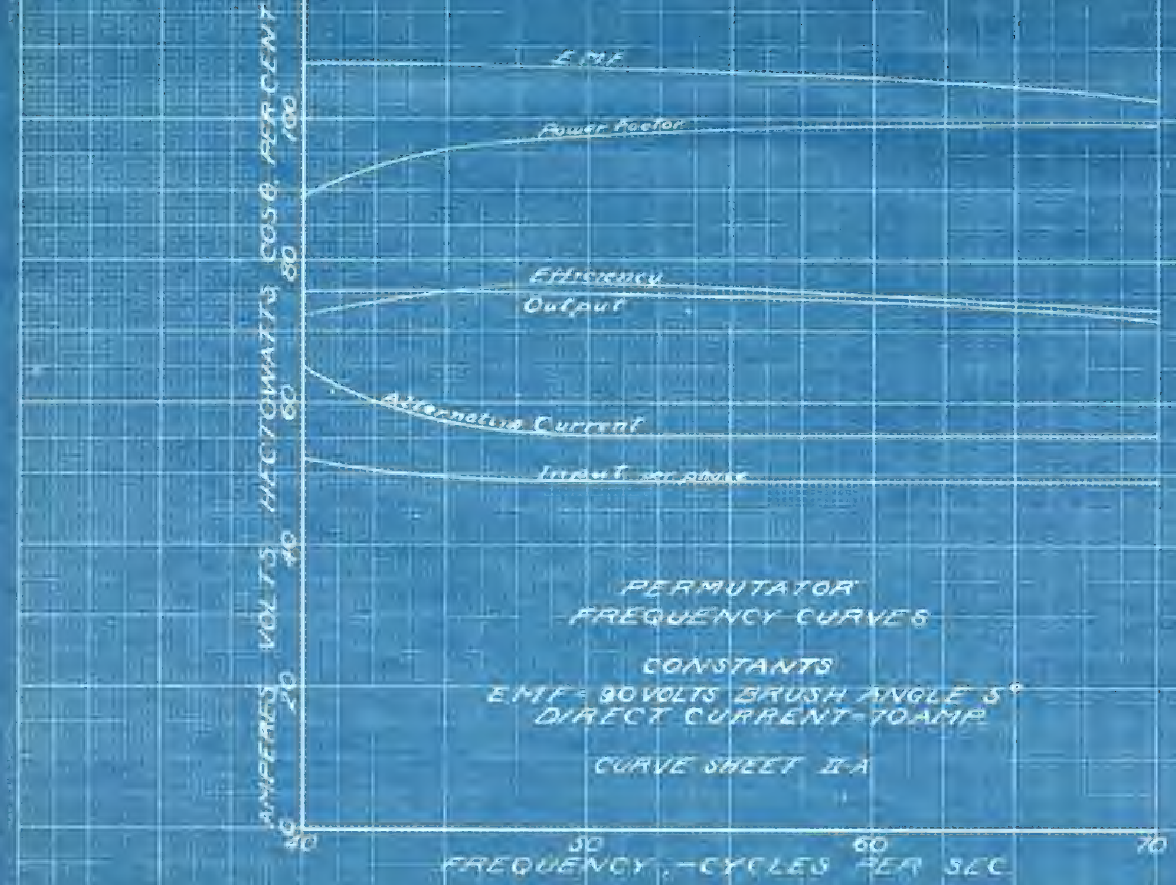

PERMUTATOR
FREQUENCY CURVES

CONSTANTS
EMF=90 VOLTS BRUSH ANGLE 5°
DIRECT CURRENT-70 AMP.

CURVE SHEET II-A

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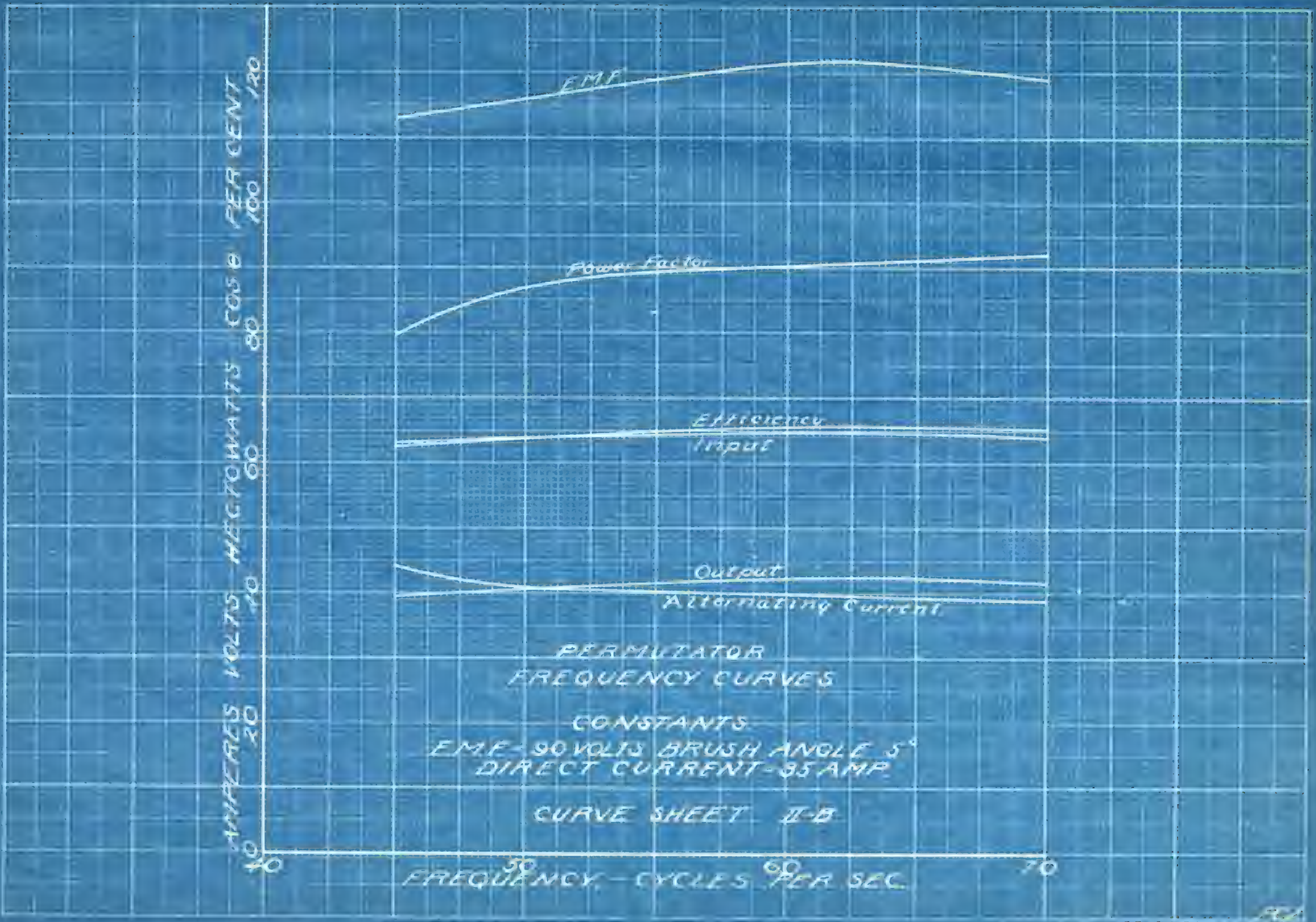

PERMUTATOR
FREQUENCY CURVES

CONSTANTS
EMF - 90 VOLTS BRUSH ANGLE 5°
DIRECT CURRENT - 35 AMP.

CURVE SHEET II-B

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PLATE III-A

PERMUTATOR

*1049

AC 60 CYCLE 90 VOLTS
DC 70 AMPERES 120 VOLTS

CONSTANTS

FREQUENCY 60~ BRUSH ANGLE 5°
DIRECT CURRENT = 70 AMP

Alternating Current					Direct Current		Eff
Volts	Amp	Watts per Ø	Watts Total	Watts Volt-Amp	Volts	Watts	%
70.1	56.5	3820	7640	3890	78.7	5450	71.2
74.9	56.0	4130	8260	4190	86.0	6020	73.0
79.7	55.9	4350	8700	4450	91.2	6380	73.3
84.6	55.5	4590	9180	4700	97.3	6810	74.3
89.6	54.9	4870	9740	4920	103.8	7260	74.4
94.6	54.4	5080	10160	5140	109.0	7640	75.2
99.4	54.0	5300	10600	5360	113.8	7960	75.1
104.5	53.9	5580	11160	5640	119.3	8350	74.8
109.5	54.0	5850	11700	5920	124.5	8710	74.5
114.5	54.5	6150	12300	6250	130.0	9100	74.0

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PLATE III-B

PERMUTATOR

#1049

A.C. 60 CYCLE 90 VOLTS DC 70 AMPERES 120 VOLTS

CONSTANTS

FREQUENCY 60~ BRUSH ANGLE 5°
DIRECT CURRENT-35 AMP.

Alternating Current					Direct Current		Power Factor	Eff.
Volts	Amp	Watts per Ø	Watts Total	Watts Volts-Amp	Volts	Watts	cos θ	%
79.8	40.5	2800	5600	3230	96.0	3360	867	60.0
84.6	39.0	3020	6040	3300	109.2	3830	914	63.4
89.7	38.0	3200	6400	3410	119.0	4170	938	65.2
94.7	38.0	3400	6800	3600	127.0	4450	945	65.5
99.4	38.0	3450	6900	3780	132.7	4650	913	67.5
104.3	38.3	3700	7400	4010	138.3	4850	923	65.5

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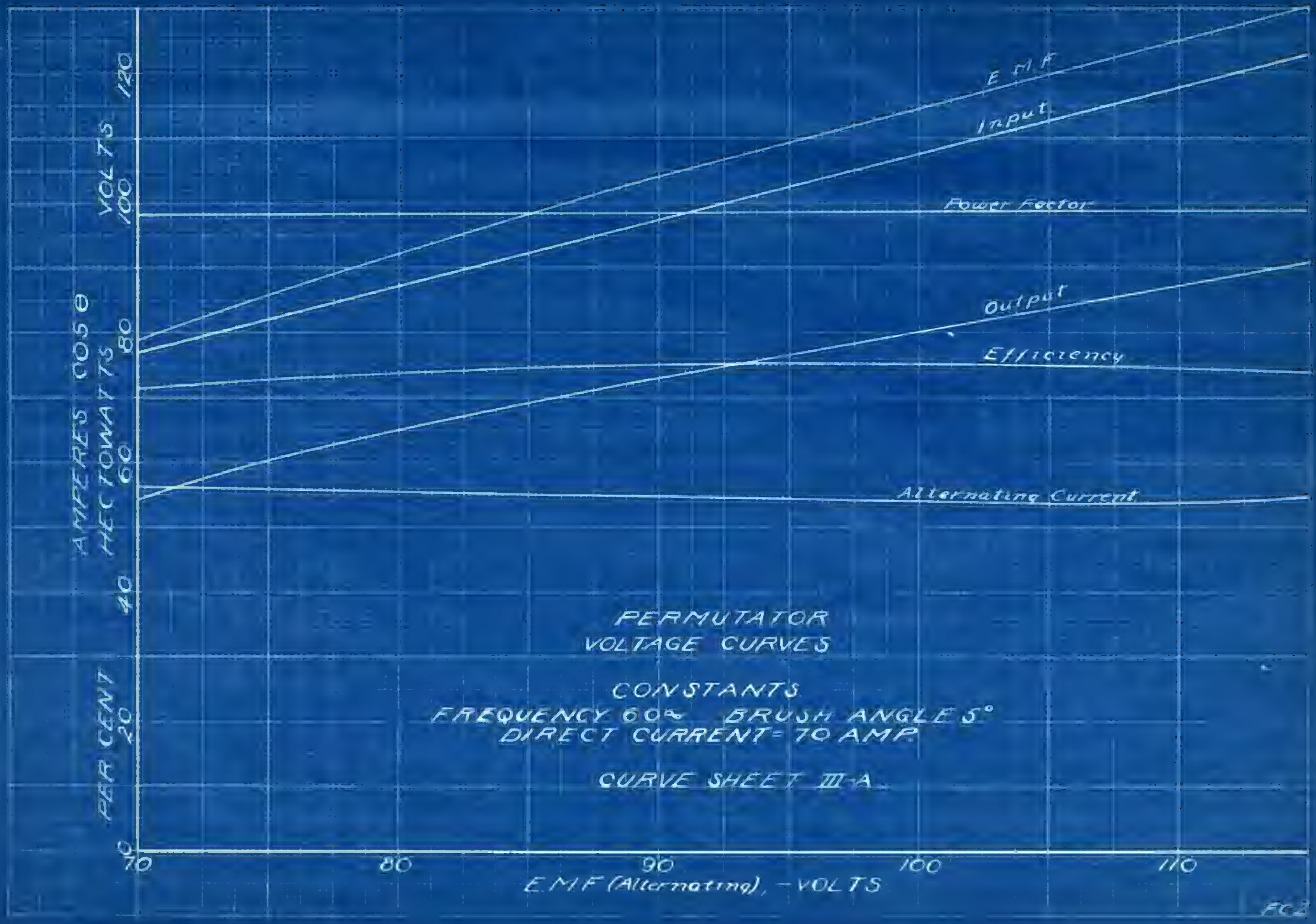
PERMUTATOR
VOLTAGE CURVES

CONSTANTS
FREQUENCY 60~ BRUSH ANGLE 5°
DIRECT CURRENT = 70 AMP.

CURVE SHEET III-A

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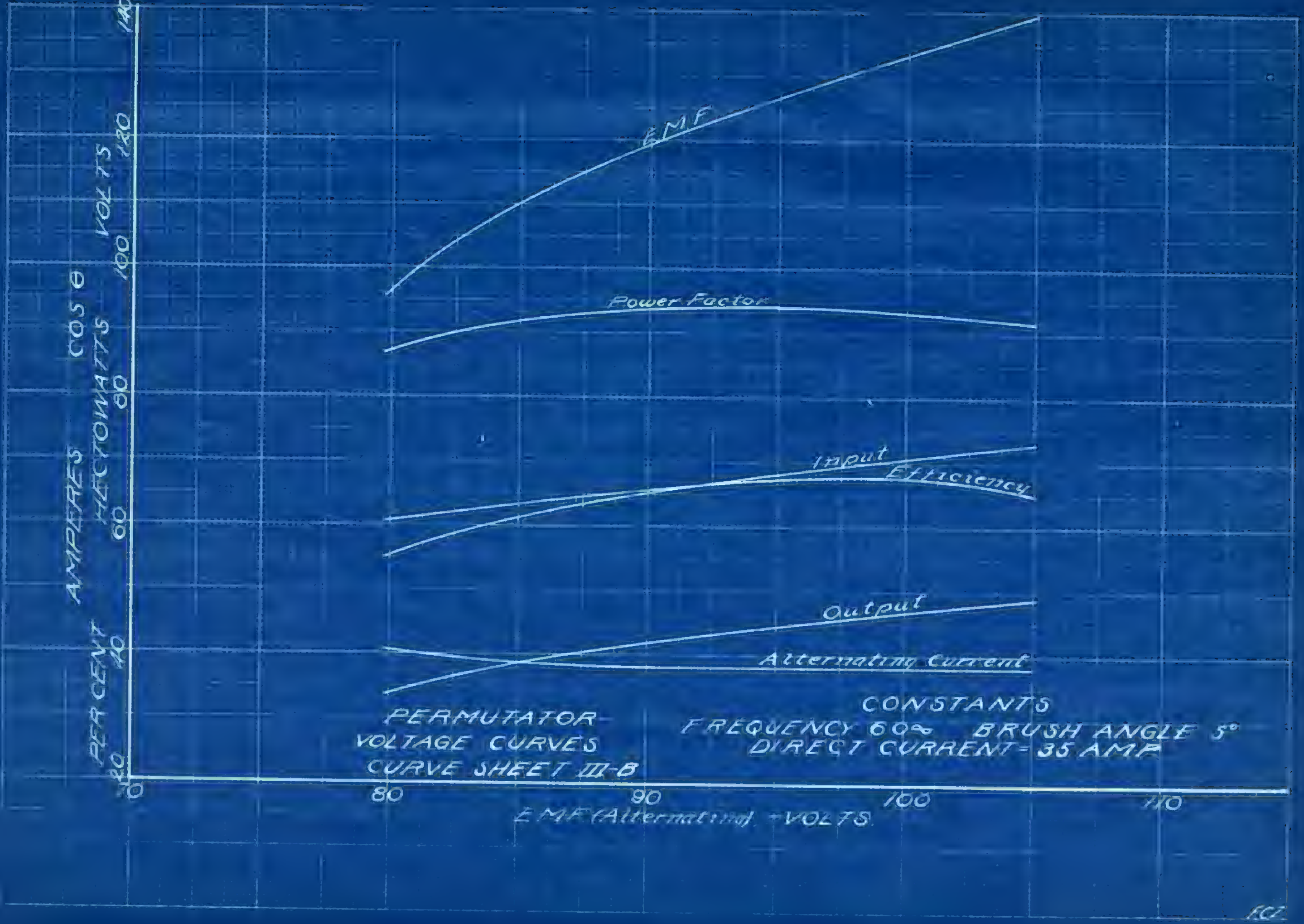

PERMUTATOR
VOLTAGE CURVES
CURVE SHEET III-B

CONSTANTS
FREQUENCY 60~ BRUSH ANGLE 5°
DIRECT CURRENT = 35 AMP.

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PLATE IV

PERMUTATOR

9049

AC 60 CYCLE 90 VOLTS
DC 70 AMPERES 120 VOLTS

CONSTANTS

E.M.F. = 90 VOLTS FREQUENCY = 60~
SYN. MOTOR SEPARATELY EXCITED

Brush Angle	Direct Current		Alternating Current				Power Factor	Ind Factor	Mag Comp
Deg.	Amp	Volts	Amp per Ø	Watts per Ø	Watts Total	Watts 90-Amp	COS θ	SIN θ	I SIN θ
	.0	112.8	14.0	630	1260	1260	500	866	12.1
0	350	102.2	29.8	2640	5280	2680	985	173	5.2
	700	93.7	52.2	4700	9400	4700	Unity	Zero	0.0
	.0	121.8	14.3	640	1280	1285	497	868	12.4
5	350	112.0	31.3	2740	5480	2840	965	262	8.3
	700	105.5	54.0	4830	9660	4860	993	100	5.4
	.0	126.5	13.5	515	1030	1215	425	906	12.2
10	350	113.9	32.2	2760	5520	2900	952	306	9.9
	700	107.7	55.5	4940	9880	5000	988	154	8.6
	0	127.0	13.4	480	960	1210	397	918	12.3
15	350	114.5	33.5	2770	5540	3020	916	401	13.4
	700	107.8	57.4	4980	9960	5170	963	270	13.5

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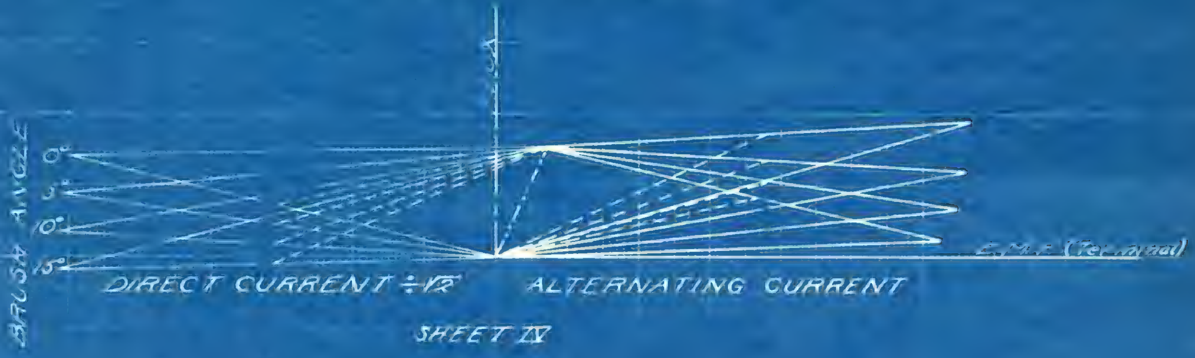
VECTOR CURRENT DIAGRAM

SCALE:- $\frac{1}{16}''$ = 1 AMP.

— FULL LOAD = 70 AMP

--- HALF LOAD = 35 AMP



SHEET IV

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on Curve Sheets II-A and II-B respectively were plotted from the above data.

PLATES III-A and III-B contain the data obtained by varying the impressed voltage for full and half load respectively. The corresponding curves will be found on Curve Sheets III-A and III-B.

The vector diagram was obtained from the data given on PLATE IV.

The data as given in PLATES II-A, II-B, III-A and III-B was obtained with the brushes leading by an angle of 5 mechanical degrees or 10 electrical degrees. The angles given on PLATE IV. are also the angles read on the scale. The excitation, however, was kept constant, and therefore these angles bear no relation to those given on the other data sheets.

In the vector diagram the impressed alternating voltage is taken as the zero vecto and the flux is shown as indicated lagging behind the e.m.f. by 90 degrees. The exciting current, as in any transformer, is the resultant current of the secondary and the primary currents. This is true for this machine because the direct current may be vectorially represented as shown. It is evident that the rectified

direct voltage is in phase with the current and that the same is true for the terminal voltage. The counter electromotive force on the alternating current side (not shown), differs from the impressed both in phase and in value due to copper drop, inductive drop and the position of the brushes.

The magnetizing current is practically constant and is represented by the double dot,dash line. Now that this remains constant it is seen that by shifting the brushes in the direction of rotation, that is,15°, 10°, 5°, etc.the direct current furnishes part of the excitation and nearly all with the brushes set at 0°. This necessarily decreases the wattless component of the alternating current and thus increases the power factor. Furthermore, an increase of load also increases the power factor, very rapidly for small loads and very slowly for large loads, the rate of change depending upon the location of the brushes. The curves on Sheet I show how the power factor is affected by the load and the position of the brushes.

The efficiency, it is seen, also increases within the limits of sparkless commutation. The maximum lead allowable for this condition is about 5° from

the neutral plane,- corresponding to 5 degrees in the data. For this condition the efficiency is a maximum and the total current is a minimum.

It is now obvious that a slight angle of lead is advantageous; for, the power factor is high, the efficiency is high and the total current is low. For these reasons the other tests were made with the brushes set at 5 degrees.

The losses consist of iron,copper and friction losses. The curve shown on Sheet I-A represents the total losses. The increase with an increase of load is due to copper loss only the iron and friction loss remaining practically constant.The voltage across the brushes decreases with the load due to copper drop.

Perhaps the effect produced by changing the impressed voltage for constant direct current output for various shaped waves on this machine would be exceedingly interesting. A good illustration of this is found on Sheets III-A and III-B which contain the curves of the terminal voltage plotted against the impressed for full load and half respectively. In the former the terminal voltage curve is seen to

be practically a straight line, in the latter, other conditions remaining the same, such is not the case. For 79 volts impressed the terminal voltage is the same for full load and half load conditions,-- the terminal voltage in the latter case rises rapidly as the impressed voltage is increased and finally increases at the same rate as under full load conditions,that is, the two curves are parallel for impressed voltages greater than normal voltage.

This characteristic is unique; for when supplied with a distorted alternating voltage, this machine may, with careful manipulation, be made to operate at full load but not at some lesser load when the impressed voltage reaches a certain low value. The explanation given below with the intention of bringing out one of the many peculiar features of this machine we believe to be correct,-- nevertheless, it is still open to question and needs verification.

Let us assume that an appreciable harmonic, say the fifth, is superimposed upon the fundamental wave. Remembering that for this machine the direct voltage is equal to the instantaneous value of the alternating voltage at some point of the wave which is fixed

by the location of the brushes. That is, if the brush

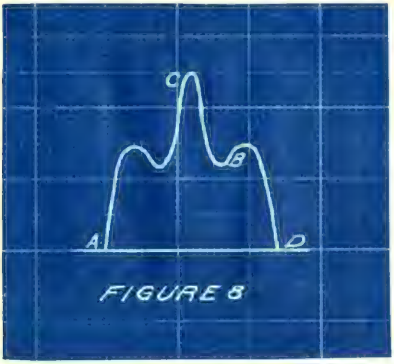


FIGURE 8

is at B (Fig. 8) the voltage is equal to the ordinate at this point and will increase or decrease as the brush moves along the curve ACB.Since either a change of excitation or a change of rotating field strength (or both) will change the angle between the two fields we may expect a corresponding change of terminal voltage if the current is kept constant.This may be brought about by varying the alternating voltage. Ordinarily, if the impressed voltage is low the motor is unstable if the brush is located between the peak at "C" and the trough at "B". If the voltage is normal this will not occur. And again, if the brushes are on the other slope the same low voltage will not cause an unstable

condition. There is one more point to consider before explaining the complete action. If the machine is carrying full load in one case and say half load in another for the same impressed voltage the brush in the former case will be, say at "C", and in the latter at "B" because the copper drop in the first case is greater and thus the excitation less.

Let us now apply these principles and possibly account for the peculiar e.m.f. curves given on Sheets III-A and III-B. It is seen that for half load the voltage drops off very rapidly when the impressed voltage is decreased below 80 volts while for full load it decreases less rapidly. As the alternating voltage decreases the field strength decreases at the same rate. The brush therefore drops back towards "C" whether the machine is loaded or not. It reaches "C" when the machine is carrying full load before it reaches the same point when carrying a less load as the voltage is allowed to decrease. In the meantime the direct voltage tends to increase and thus explains why the e.m.f. curve for full load is practically a straight line in the region under consideration.

THE ROUGE-FAGET PERMUTATOR.

When the voltage becomes sufficiently low the brushes , when the machine is carrying half load, unlike the former case, move very rapidly from "B" towards "C", and the excitation being very weak as the brush moves in the trough, allows the machine to hunt and fall out of step. That is, the machine may carry a certain load for some low voltage, having a distorted wave but not some load of lesser value. This was experienced in the laboratory when performing the test from which the data in PLATE III-B was obtained. A change in frequency brings about results much the same but to a lesser degree. The curves are given on Sheets II-A and II-B.

THE ROUGE-FAGET PERMUTATOR.

SPECIAL FEATURES.

For a constant frequency of 60 cycles per second the synchronous motor of this machine, when carrying no load, will not drop out of step until the direct voltage reaches the low value of 29 volts when the auxiliary resistance is not in circuit, otherwise, when in circuit it is 36 volts; in other words, the minimum exciting current is one half ampere. These values are necessarily greater if the frequency is variable. In practice so low a voltage is impossible and the frequency although variable to a slight extent, depending upon the prime mover, could not vary sufficiently to cause hunting much less dropping out of step. In fact hunting is practically impossible even at full load, or for heavy overloads when the alternating voltage is normal.

The patentees claim that some of their machines may be operated as inverted permutators, that is, change from direct current to alternating current. This particular permutator is not made to fulfill this condition, however, it will start on a very low voltage, but large current (100 amperes), and when once started will accelerate very rapidly and unless the current is reduced to a few amperes it will race. That is, the motor field

tends to fall into step with the rotating field in the core which leads the armature field continually for all speeds. As a caution then, under no circumstances should this particular permutator be operated in parallel with other direct current generating apparatus without having in circuit some safety device which would open the direct current circuit. One of two things would happen; either the machine would short-circuit the line, or worse, the revolving parts would be destroyed if for some reason the alternating current circuit were opened.

The single phase permutator has been constructed and operates very satisfactorily. This permutator operates as single phaser on no load, refusing however to operate under load. If the impressed voltage is sufficiently increased it may be made to operate on small loads but with considerable difficulty.

The auxiliary resistance which accompanies this machine should always be connected in series with the armature when the machine is lightly loaded or when the terminal voltage is above normal value; for,if the armature is directly connected the coils will overheat beyond a safe workable temperature.

THE ROUGE-FAGET PERMUTATOR.

CONCLUSION.

The superiority of the permutator the reader has probably realized from what has already been said. Let us compare this machine with the rotary convertor in regard to its operating performance, weight, cost, in fact, from all possible aspects.

We notice in the first place that its starting action is very simple and when used to feed into a direct current system simply requires the closing of the supply switch and then the feeder switch after synchronous speed has been reached. If separately excited, which would be the case in general, it will always come up in the right direction. The synchroscope is therefore unnecessary when starting and the time required for the machine to reach synchronism is only a few seconds,---- the direct current voltmeter being the only indicator needed to indicate synchronous speed. All starting apparatus is thus eliminated.Its operation being so simple, when starting and when running, greatly reduces the cost of labor.

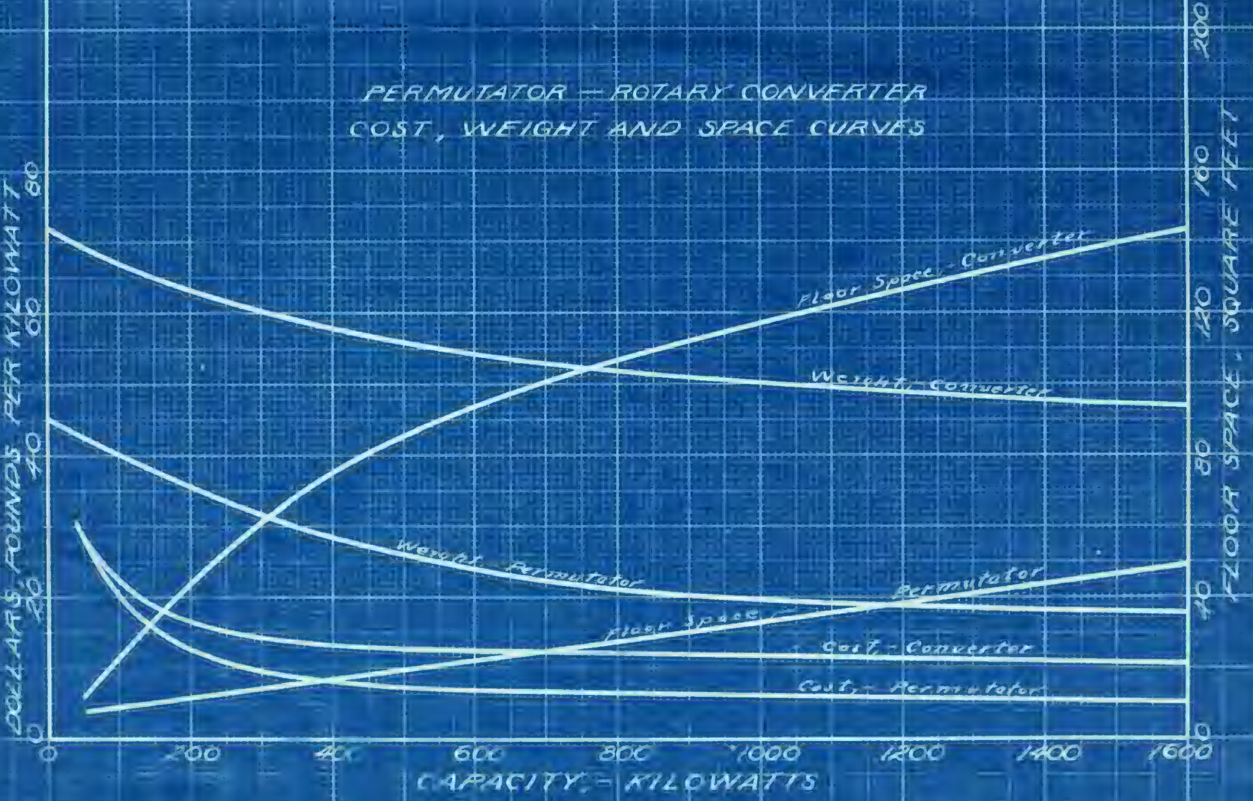
The statement has been made that this machine would operate without serious sparking at 50% overload. Were it not for the small resistance wires used as com-

mutating resistances this value,we do not doubt,could be increased to a much higher value.The manufacturers claim the overload capacity for constant operation may reach the high value of 100%. Of course this depends upon the initial rating of the machine.

We have shown that the permutator may be operated entirely satisfactorily for a large range of frequencies. This is not an essential feature but one of interest.

Perhaps the most important advantage this machine has over the converter lies in the fact that transformers are entirely dispensed with. The possibility of obtaining say 550 volts direct current from an alternating current line of 5000 volts is certainly a long step towards ideal electric power transmission. There is no reason why the coils of the machine can not be oil cooled and insulated as is done in transformers. This would allow the alternating current voltage applied to the machine to reach the high voltages used in power transmission.

The curves shown on the following page give some idea of the relative values of weight, floor-space and cost of permutators and rotary converters. We have selected for comparison the low voltage con-


PERMUTATOR — ROTARY CONVERTER
COST, WEIGHT AND SPACE CURVES
DOLLARS, POUNDS PER KILOWATT
0
20
40
60
80
FLOOR SPACE, SQUARE FEET
0
40
80
120
160
200
CAPACITY, KILOWATTS
0
200
400
600
800
1000
1200
1400
1600
Floor Space - Converter
Weight - Converter
Weight - Permutator
Floor Space - Permutator
Cost - Converter
Cost - Permutator

verter for 25 cycles, that is, one used for lighting purposes. The same curves apply approximately to railway sets. The cost given for the permutators does not include the duty. To give the reader the benefit of the doubt we have not included the cost, floor space and weight of the transformers which are used in connection with converters.

One is impressed with the fact when comparing these curves, that, had the machine no other advantages, these, which are so plainly evident are sufficient to warrant consideration. The cost of the substation equipment and its upkeep would be greatly reduced, more than 50% in round numbers. But why consider a railyway substation at all? The small weight and floor space and the absence of transformers makes it possible to place the permutator upon the car itself when used for either suburban or interurban lines and thus eliminate the substation with its costly equipment and feeder system. That is, we may use as a limit the high voltage allowable on the trolley between towns and obtain 600 volts direct current at the motors. The same equipment may be used in the city, where high voltage on the trolley is prohibited, by

placing along the line, small transformer substations wherein the high voltage may be reduced say to 900 volts. This arrangement makes it possible to use the direct current series motor on the same voltage as before. Stated more briefly, by placing the small permutator upon the electric locomotive the costly substation with all its fixed charges is done away with, the costly feeder system is eliminated, the losses are greatly decreased and the insufficient alternating series motor is replaced by the more efficient and suitable direct current series motor.

The power factor and especially the efficiency of the permutator is as good as in any other apparatus. The permutator under consideration, although having an efficiency of 75%, must be remembered is only a 9 K.W. machine, and comparable with a converter of the same size. The manufacturers claim that for the large machines they are able to obtain efficiencies as high as 96%.

By suitably arranging the primaries and secondaries of these permutators, so that they may be moved relatively to each other, it is possible to obtain perfect regulation. A device which would change the angle of lead of the brushes would make it poss-

ible to change the power factor.

Many of the advantages have been based upon our observations and tests. Having done this we have the privilege of stating the disadvantages on the same grounds. The machine is certainly a noise generator as well as an electric generator. This fault, however, is not interlinked with its electric features but rather with its mechanical construction.The undesirable noise is due to the poor commutator construction and must not therefore be related to the permutator as one of its electrical characteristics. In general, the only serious disadvantage is the use of revolving brushes which need a special brush holder to nullify the effect of centrifugal forse.

The following advantages in tabulated form then are:-

1. Self starting,- action simple.
2. No starting apparatus necessary.
3. Synchronous speed attained within a few seconds.
4. Cannot hunt.
5. Operation simple.
6. Less attendance required.

7. Overload capacity large.
8. Adaptable to frequencies between wide limits.
9. Transformers unnecessary.
10. Suitable for any voltage.
11. Perfect parallel operation.
12. Small weight.
13. Low cost.
14. Small floor space.

Perhaps we have dwelt too long upon the commercial aspect of this machine which undoubtedly will replace the converter within a few years;however,since it is a machine of commercial value we did not wish to neglect those features which surpass in many respects those of the converter. Remembering that we have compared two machines,---- one whose development is about complete, the other whose development has just begun, we may feel assured that the "Rectifying Apparatus" is the beginning of a new era in electric power engineering.

FINIS.

THE ROUGE-FAGET PERMUTATOR.

APPENDIX.

For various reasons four auxiliary coils were wound upon the core. By means of these coils it is possible to determine the per cent of the total flux which enters the armature (66.6%), the distribution of the flux and other constants. The following information may be of value.

One winding consisting of one coil contains 15 turns of #28 (B&S) double cotton covered wire and has a pitch of seven slots. Its resistance is .940 ohms. Another winding consisting of 5 coils, each having a pitch of 7 slots, contains 30 turns or 6 turns per coil of the same size wire. These coils are lap wound and advance by one slot. Another coil, consisting of ten turns of the same wire, is wound between one slot and the outer periphery of the core. The fourth coil, consisting of 25 turns of #36 (B&S) wire, is wound between one slot and the inner periphery of the core.

The drawing under separate cover contains the principle dimensions necessary for determining any of the electrical or magnetic constants. The same are herewith given for future reference.

THE ROUGE-FAGET PERMUTATOR.

CORE.

Diameter, inside	20 cm.
Diameter, outside	36 cm.
Breadth	11.5 cm.

SLOTS.

Number	45
Length	4.75 cm.
Breadth	1.05 cm.

(End circular, radius .53 cm.)

Minimum thickness of core between slot and inner periphery	.28 cm.

COMMUTATOR.

Number of segments	90
Diameter	14 cm.
Commutating resistance	.125 ohms at 16° C.

BRUSHES.

Material	Carbon.
Number of sets	4
Number per set	3
Breadth	3 cm.
Thickness	.9 cm.

THE ROUGE-FAGET PERMUTATOR.

ARMATURE.

Number of slots	32	
Depth of slot	1.9	cm.
Length along core	10.0	cm.
Breadth of slot along core	1.05	cm.
Length of core (external)	20.3	cm.
Length of core (internal)	16.3	cm.
Diameter (external)	19.8	cm.
Diameter (mean internal)	12.3	cm.

WINDING ON ARMATURE.

Style	Lap	
Front pitch	9	
Back pitch	-7	
Resistance at working temperature	59	ohms.
Resistance of armature rheostat	15	ohms.
Resistance of core winding across one phase as measured by direct current at full load	.1155	ohms.

The position of positive brush when terminal #1 (see winding diagram) is positive, (maximum) is at the segment connected to this terminal, etc.

Direction of rotation is clockwise when looking down upon the machine.

Weight, 300#.